The Uptake and Use of ^{15}N-Nitrogen in Young and Mature Field-Grown Highbush Blueberries

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Abstract

The effect of nitrogen (N) fertilization rate on growth, yield and N partitioning in young and mature field-grown 'Bluecrop' was studied. Depleted ^{15}N-$(NH_4)_2SO_4$ was applied in the first year (2002) and non-labeled fertilized in the second year (2003). Only first-year results are reported here. Three N fertilizer rates (0, 100 and 200 kg N ha $^{-1}$) and two in-row spacing treatments (0.45m and 1.2m) were studied in the mature planting. Four N fertilizer rates (0, 50, 100 and 150 kg N ha $^{-1}$) were applied in the establishment year of a new planting, spaced at 1.2m. In both studies, the N fertilizer was applied as a triple split (33%:33%:33%) from April through June. Plants were destructively harvested from the field and divided into parts on six dates from February to October 2002. Plant parts were analyzed for dry weight, N and ^{15}N concentration (%) and nitrogen derived from fertilizer (NDFF) calculated. In the mature planting, N fertilization rate had no effect on plant dry weight, but plants at 1.2m were larger than those at 0.45m. Plants fertilized with 200 kg N ha $^{-1}$ had a higher total N content in July and September than unfertilized plants. Percent NDFF increased from 3% in April to 23% in September, with no treatment effect. Fertilizer recovery was initially slow (only 1 to 2% recovery two weeks after the first split), but increased to 22% to 43% in September depending on in-row spacing and N rate; plants spaced at 0.45m recovered a higher percentage of the fertilizer. Yield was not affected by N fertilization rate, but was 35% higher at 0.45m than at 1.2m. In the new planting, established using two-year-old plants, N rate affected plant dry weight, total nitrogen content, percent NDFF, and fertilizer recovery. By October, plants fertilized with 50 kg of N ha $^{-1}$ had the largest dry weight and N accumulation. Ammonium toxicity was observed in plants fertilized with 100 and 150 kg N ha $^{-1}$. Percent NDFF was 60% and 67% for the 50 and 100 kg N ha $^{-1}$, respectively. Fertilizer recovery reached its maximum in October (17% and 10% for the 50 and 100 kg of N ha $^{-1}$).

INTRODUCTION

Blueberry production has been increasing steadily in Oregon and Washington, USA with approximately 80 to 120 ha being planted annually, on average, over the last ten years. Growers have generally been applying recommended rates of nitrogen (N) fertilizer, 110 kg

N ha $^{-1}$ for mature plantings at 1.2m by 3m (Strik and Hart, 1991; Strik et al., 1993) or have been applying much higher rates, depending on their production practices (Martin et al., 2001).

Various studies have been completed on the effect of rate of nitrogen fertilization on the growth and yield of mature blueberry plants. In a study on 'Bluecrop', comparing a nitrogen rate of 75 kg N ha $^{-1}$ to an unfertilized control (no fertilizer for 5 years), plants fertilized with a split application of N had the highest yield (Hanson and Retamales, 1992). Clark et al. (1998) found that yield of 'Collins' was not affected by fertilization rates of 22 and 112 kg N ha $^{-1}$; however, applications of 67 and 134 kg N ha $^{-1}$ reduced yield compared to the 22 kg N ha $^{-1}$ treatment over two years.

Throop and Hanson (1997) showed that mature blueberry plants absorbed fertilizer N most efficiently during active growth between late bloom and fruit maturity; however, only 8% of the fertilizer was recovered two weeks after application. Mature 'Bluecrop' fertilized with 40 kg N ha $^{-1}$ of urea before bud break, recovered 32% of the fertilizer N by the following fall (Retamales and Hanson, 1989). Previous researchers have suggested that multiple applications of fertilizer nitrogen would be necessary to maintain sufficient soil N levels throughout the period of high demand.

No work has been published to date on N fertilizer uptake and partitioning of young blueberry plants.

The objectives of our study were to determine the impact of rate of nitrogen fertilizer application on N uptake, partitioning, growth, and yield of mature blueberry plants at an in-row spacing of 0.45m or 1.2m and of young blueberry plants.

MATERIALS AND METHODS

Mature planting

An existing 'Bluecrop' planting at the North Willamette Research and Extension Center (NWREC), established in October, 1993, was used for this study. The planting site was fumigated with methyl bromide/chloropicrin, with sawdust and fertilizer (66 kg·ha^{-1} of N) incorporated prior to planting two-year-old container stock. Plants were spaced at 0.45m or 1.2m in the row with 3m between rows.

The N fertilizer rate treatments were: 0, 100, or 200 kg N/ha applied as a triple split (33% April 9; 33% May 9; and 33% June 17, 2002); the equivalent rates per plant were 0, 14, and 28 g · plant $^{-1}$ at 0.45m and 0, 37, and 74 g · plant $^{-1}$ at 1.2m. ^{15}N-depleted ammonium sulfate [$(NH_4)_2SO_4$] fertilizer was used. All treatment plots were fertilized with 35 kg·ha^{-1} of P and 66 kg·ha^{-1} of K each spring. The treatments were arranged in a randomized complete block design with 3 replicates.

One plant per plot was destructively harvested on each of 5 dates from spring to fall 2002. Plants were dug to ensure recovery of as much of the root system as possible. Roots were washed. Plants were separated into their parts: current season growth, 1-year-old, 2-year-old and older wood, crown, roots, leaves, floral buds, vegetative buds, flowers, fruit and senescing leaves depending on the stage of development. Each part was dried and dry weight measured and then sub-samples were ground and total N, and ^{15}N concentration measured.

Plots were harvested by an over-the-row rotary machine harvester (Littau Harvesters Inc., Stayton, Ore., USA) in 2002. Data collected included yield and average berry weight (25 berries per harvest).

Young planting

A planting of 'Bluecrop' was established at the NWREC on March 27, 2002. Sawdust and fertilizer (66 $kg{\cdot}ha^{-1}$ of N) were incorporated prior to planting two-year-old container stock. No surface sawdust mulch was applied. Blossom buds were pruned off the plants at planting. Plants were spaced at 1.2m in the row with 3m between rows.

The treatments were four different nitrogen (N) rates: 0, 18.6, 37.2, or 55.8 $g \cdot plant^{-1}$ (equivalent to 0, 50, 100, or 150 kg N ha^{-1}, respectively). The N fertilizer was applied as a triple split (33% April 11, 33% May 20, and 33% June 27). ^{15}N-depleted ammonium sulfate $[(NH_4)_2SO_4]$ fertilizer was used. All treatment plots were fertilized with 35 $kg{\cdot}ha^{-1}$ of P and 66 $kg{\cdot}ha^{-1}$ of K each spring. The treatments were arranged in a randomized complete block design with 3 replicates.

Plant growth, dry weight, N, and ^{15}N partitioning data were collected as mentioned for the mature planting.

Soil samples were collected on each plant sampling date and pH determined.

RESULTS AND DISCUSSION

Mature planting

Total plant dry weight was significantly affected by in-row spacing, but not by N fertilization rate. Thus, the data in figure 1 are averaged over N fertilizer rate. Plants spaced at 1.2m were larger than those spaced at 0.45m (Figure 1). Dry weight increased over time at both in-row spacing treatments; the dry weight data for October were taken before plants were pruned. The percentage of dry weight allocated to roots was 27% and 25% for plants spaced at 0.45m and 1.2m, respectively in September. Proportion of dry mass partitioned to roots in September was not related to rate of N fertilization (data not shown). The crown and roots accounted for 43% to 52% of total plant biomass, similar to the amount reported by Retamales and Hanson (1989).

Plant nitrogen content increased throughout the season, with the largest accumulation at the end of the season in September. Plants spaced at 1.2m accumulated more N (27 $g \cdot plant^{-1}$ on Sept. 11) than those at 0.45m (15 $g \cdot plant^{-1}$), due to their larger size. Nitrogen fertilization rate had a significant effect on total plant N content on July and September ($P <$ 0.05; Figure 2). The concentration of N (%N) was affected by N fertilization rate, especially in young tissues (shoots, fruit, and 1-year-old wood), thus affecting the total N content in the plant (data not shown).

Fertilizer N was not taken up very quickly at either spacing (Figure 3). Two weeks after the first split of fertilizer N was applied, plants had recovered only 1 to 2% of the applied fertilizer; this recovery is similar to the 1% fertilizer recovered two weeks after an application before bud break reported by Throop and Hanson (1997). In our study, fertilizer recovery increased to 4 % in May (two of the three splits applied), 12 to 17% in July (two weeks after last split applied), and 22 to 43% in September, at the end of the season. The amount of fertilizer N in plants was at a maximum for the season in September (our last plant harvest date in the season of application); thus our results differ from those of Retamales and Hanson (1989) who found that fertilizer N content in plants peaked three weeks after a single application of labeled urea before bud break. Perhaps in our milder climate the period of most rapid growth is later than in Michigan or shoots grow for a longer period of time. Percent NDFF increased from 3% in April to 23% in September, with no treatment effect.

Plants spaced at 0.45m and fertilized with 100 or 200 $kg \cdot ha^{-1}$ of N took up 43% or 31% of the fertilizer including harvested fruit, respectively, by September. At the 1.2m in-row spacing, plants recovered 23% of the fertilizer N at the 100 or 200 $kg \cdot ha^{-1}$ of N rate. Our recovery rates are similar to the 32% reported for mature blueberry (Retamales and Hanson, 1989). In September, leaves accounted for 34 to 46% of the total fertilizer N in the plant, similar to the 32% reported by Retamales and Hanson (1989).

The higher fertilizer uptake at the 200 kg N/ha rate may have been "luxury" uptake. The N concentration of the leaves of unfertilized plants averaged 0.57 %N at senescence (Nov. 11) whereas the leaves of fertilized plants averaged 0.76 and 1.0 %N at 100 or 200 $kg \cdot ha^{-1}$ of N, respectively; the percent of total N in the leaves that came from the fertilizer averaged 41% and 49% at 100 or 200 $kg \cdot ha^{-1}$ of N, respectively. Thus, a considerable amount of fertilizer N (from 3 to 10 $kg \cdot ha^{-1}$ of N) was "lost" at leaf senescence – this would, however, be returned to the soil pool of N.

Total N harvested in the fruit averaged 12 and 9 $kg \cdot ha^{-1}$ for the 0.45m and 1.2m spacing, respectively. The percentage of N derived from the fertilizer (NDFF) in the harvested fruit was 28% for the 100 $kg \cdot ha^{-1}$ of N treatment at either in-row spacing. However, plants fertilized with 200 $kg \cdot ha^{-1}$ of N had 42% NDFF in fruit at the 0.45m spacing and 35% NDFF at 1.2m. Thus, the amount of fertilizer N harvested in the fruit ranged from 2 to 6 $kg \cdot ha^{-1}$ (data not shown).

In-row spacing had no significant effect on N concentration of fruit. However, N fertilization significantly increased N concentration of harvested fruit: Fruit from unfertilized plants averaged 0.63 %N whereas fruit from fertilized plants averaged 0.84 and 0.92 %N when fertilized with 100 or 200 $kg \cdot ha^{-1}$ of N, respectively. Thus higher rates of N fertilization can increase N content of fruit, despite relatively little fertilizer being taken up before the fruiting season; it is not known how this would impact fruit quality.

Yield and berry weight in 2002, the first year N fertilization treatments were imposed were not affected by N fertilization rate, only by in-row spacing. Unfertilized mature 'Bluecrop' plants in Michigan did not have reduced yield, compared to those fertilized with 75 $kg \cdot ha^{-1}$ of N until year three (Hanson and Retamales, 1992). The high-density planting (0.45m) had 35% more yield per hectare than the 1.2m spacing, 14 t/ha compared to 10 t/ha (averaged over fertilization rate). We have documented higher yields of mature, high density 'Bluecrop' plantings in the past (Strik and Buller, 2002).

Young planting

The pH of the potting soil of the plants used in this study was 4.3. The initial pH of the field before planting and treatments were imposed was 4.9 (March 2002). Fertilization with ammonium sulfate decreased the soil pH during this study to 4.0 in October compared to 5.1 for the un-fertilized treatment.

Nitrogen fertilization rate affected plant growth (dry weight) over time (Figure 4). Differences among treatments were observed as early as June, when total plant dry weight was reduced in plants that received 0 or 150 $kg \cdot ha^{-1}$ of N compared to those that received 50 or 100 $kg \cdot ha^{-1}$ of N. By the end of the first growing season, plants fertilized with 50 $kg \cdot ha^{-1}$ of N had the largest accumulation of dry weight (Figure 4). Plants fertilized with 100 and 150 $kg \cdot ha^{-1}$ of N showed severe signs of NH_4 toxicity, with 17% and 55% of the plants dying by October, respectively. In July, plants showing symptoms of toxicity had very high levels of NH_4 in their shoots compared to the other treatments (data not shown).

The top-to-root ratio was 1.2, 1.6, 2.1, and 1.5 for the 0, 50, 100, and 150 $kg \cdot ha^{-1}$ of N treatments in October, respectively. Unfertilized plants had a lower dry weight of leaves and shoots than those fertilized with 50 $kg \cdot ha^{-1}$ of N. Plants fertilized with 150 $kg \cdot ha^{-1}$ of N had a lower total plant dry weight as a result of less weight in all plant parts.

At planting time, the initial total plant nitrogen content was 335 mg per plant. Total N increased during the first growing season, and was affected by N fertilization rate (data not shown). Plants that received 50 or 100 $kg \cdot ha^{-1}$ of N accumulated 4550 mg and 4025 mg of N per plant, respectively. Plants that were not fertilized with N accumulated only 1894 mg of N per plant. Plants fertilized with 150 $kg \cdot ha^{-1}$ of N accumulated 2318 mg of N per plant.

Leaf N concentration for the N fertilization treatments on July 24 was 1.4%, 2.8%, 2.8%, and 3.8% for the 0, 50, 100, and 150 $kg \cdot ha^{-1}$ of N treatments, respectively. Thus, plants that were not fertilized were deficient in N in late July; plants fertilized with 50 and 100 $kg \cdot ha^{-1}$ of N had normal leaf N concentrations, and the leaves from plants fertilized with 150 $kg \cdot ha^{-1}$ of N had a high N concentration due to poor shoot growth (Strik and Hart, 1991).

There was very little uptake of fertilizer N two weeks after the first application (Figure 5). Less than 1% of the fertilizer applied was recovered by plants at the end of April. The content of N derived from the fertilizer increased in the plants through October (Figure 5); this was also the time of greatest percent NDFF. The highest percentage of fertilizer recovery occurred in plants fertilized with 50 $kg \cdot ha^{-1}$ of N (17% in October). Plants fertilized with 100 $kg \cdot ha^{-1}$ of N recovered 10% of the fertilizer applied by October. Even though plants took up only 9 to 10 $kg \cdot ha^{-1}$ of N, this fertilizer N accounted for 60% to 67% of the total N in the plant (data not shown). Thus young blueberry plants do not require much fertilizer N in the planting year.

There was a large treatment effect on N concentration in the leaves at senescence. In un-fertilized plants, leaves senesced with a low concentration of N (0.5 % N), compared to 2.4 to 3.7 % N in the fertilized treatments. Thus un-fertilized plants appear to have re-mobilized N from leaves to storage tissues (~ 6 $kg \cdot ha^{-1}$ of N). In the fertilized treatments, 46% to 51% of the fertilizer N in the plant in October was present in the leaves. Plants that were fertilized with N also had a higher concentration of P, K, Ca, Mg, Mn, and C in leaves at senescence (data not shown).

CONCLUSIONS

There was no effect of N rate on yield or berry weight in the first season on this study; however an effect would be expected in subsequent years. Fertilizer recovery by plants was initially slow and did not peak during the season – rather, recovery was highest in the fall. This indicates that plants were able to take up the fertilizer N more than three months after application. Thus, fertilizer N was still present in the soil (a clay loam) and had not totally been leached out of the rooting zone (soil N data are not presented here). Our data support the advantage of providing N fertilizer to plants in a split application to maintain N levels throughout the period of high demand.

When we calculated net fertilizer recovery (^{15}N recovered by plants minus the ^{15}N fertilizer present in harvested fruit and leaves at senescence), plants spaced at 0.45m had a higher net recovery (24% to 33% when fertilized with 200 or 100 $kg \cdot ha^{-1}$ of N, respectively) than those spaced at 1.2m (17% regardless of N rate). Thus, plants at a higher density seem more efficient at taking up fertilizer N than those at a wider spacing implying that recommended N fertilizer application rates should not be proportional to planting density as has been done in the past (Strik and Hart, 1991).

Young plants were much more sensitive to under- and over-fertilization in our study than the mature plants because they did not have a lot of stored N reserves to serve as a "buffer" and the young root system was very sensitive to fertilizer "burn". In new plantings, N fertilizer should likely be applied in several split applications, at a low rate, to meet N demand yet minimize risk of harming young plants.

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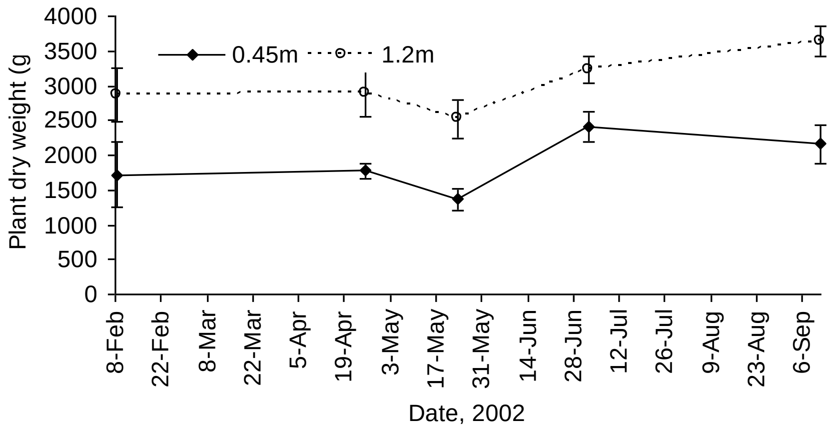

Figure 1. Plant dry weight of mature ‘Bluecrop’ plants at an in-row spacing of 0.45m or 1.2m in 2002, averaged over nitrogen fertilization rate. Mean ± SE.

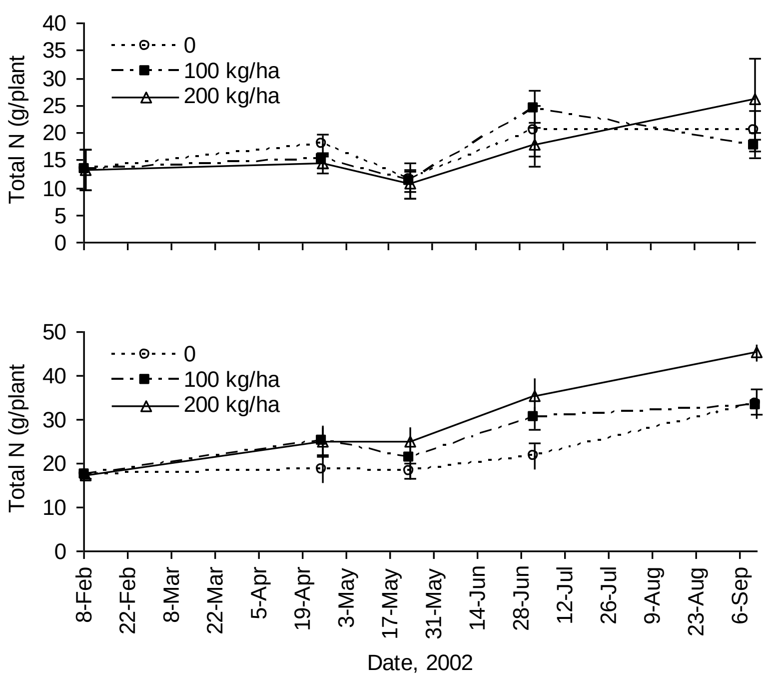

Figure 2. The effect of nitrogen fertilization rate at two in-row spacings A. 0.45m and B. 1.2m on total N content of mature ‘Bluecrop’ in 2002. Mean ± SE

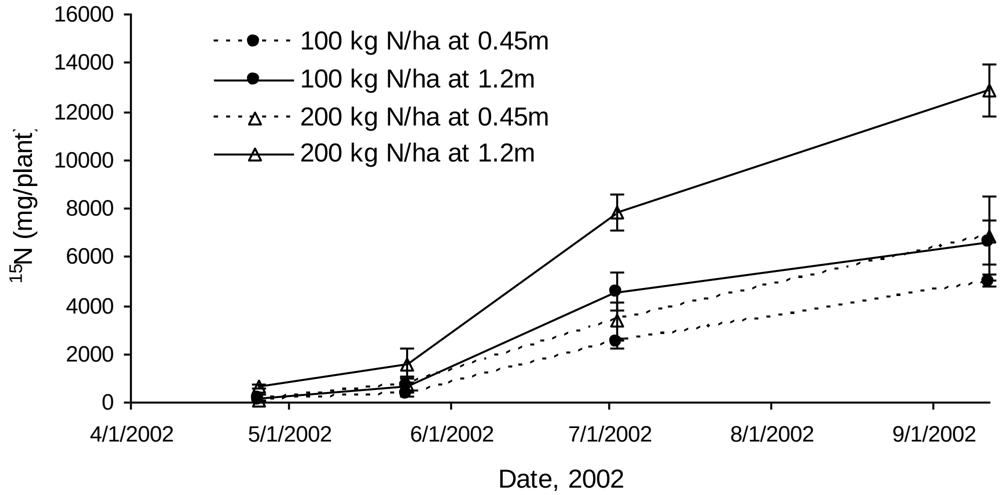

Figure 3. The effect of nitrogen fertilization rate at two in-row spacings on total N content from the fertilizer in mature 'Bluecrop' in 2002. Mean ± SE

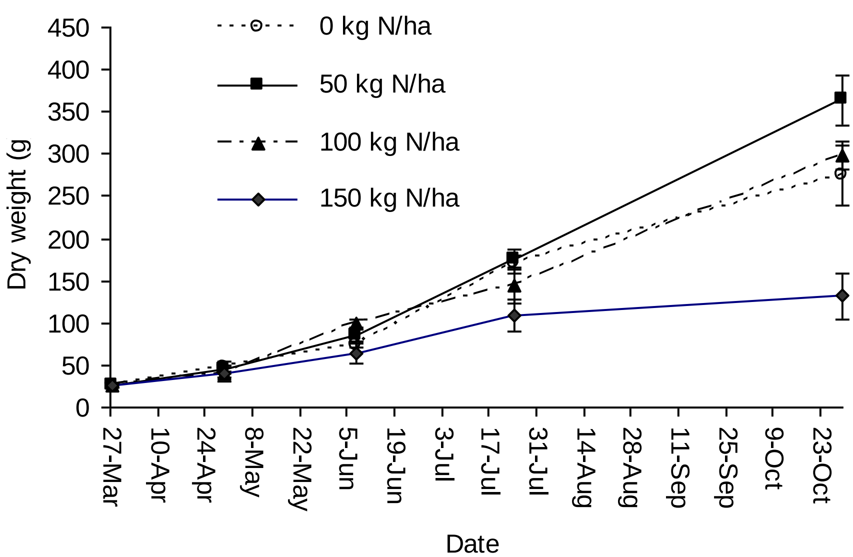

Figure 4. Plant dry weight of 'Bluecrop' in the establishment year (2002) as affected by N fertilization rate.

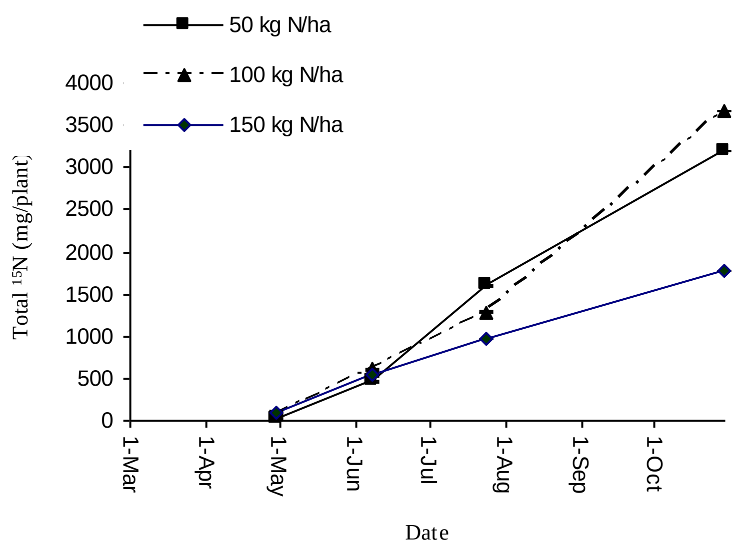

Figure 5. The effect of nitrogen fertilization rate on total N content from the fertilizer of 'Bluecrop' in the establishment year, 2002. Mean ± SE